EUR 4639 e
Part 2 of 4

COMMISSION OF THE EUROPEAN COMMUNITIES

HFR INFORMATIONS FOR USERS

Survey of the high flux facilities in the HFR Petten, selected for HTGR materials testing

by

P.R. ZEISSER

1972

Joint Nuclear Research Centre
Petten Establishment - Netherlands

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The report consists of four parts, each dealing with a different aspect of the subject: included is general information on the reactor and its performance, together with isotope production and ancillary facilities and the means available for materials testing for water and for high temperature reactors.

Special attention is focussed on the devices recently developed in the field of direct in-pile measurements, in particular for the study of the mechanical properties of various nuclear materials exposed to high neutron flux densities.

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ABSTRACT

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KEYWORD

HFR
IRRADIATION DEVICES
CAPSULES
IRRADIATION PROCEDURES
MATERIALS TESTING
MEASURING METHODS

C.C.R.

Petten Establishment
Irradiation Technology

SURVEY OF THE HIGH FLUX FACILITIES IN THE HFR PETTEN, SELECTED FOR HTGR MATERIALS TESTING

by

P.R. Zeisser

EUR 4639-2

1. INTRODUCTION

The present paper intends to give a brief survey on the High Flux Reactor of the C.C.R. Petten, its main facilities and corresponding irradiation devices available in view of its utilization for HTGR materials testing irradiation experiments.

In this concise edition no special attention has been given to general features such as HFR damage flux, requirements with respect to graphites and fuels of the different reactor projects etc. Facilities specially installed for applications outside the HTGR field, such as isotope carriers, water loops etc. have been disregarded.

All information is presented in the form of illustrations, tables, diagrammes and introduced, highlighting particular features, restrictions, definitions and subjects adjacent to the one treated. A repartition into three chapters is made, dealing with the reactor, the irradiation devices and the irradiation projects.

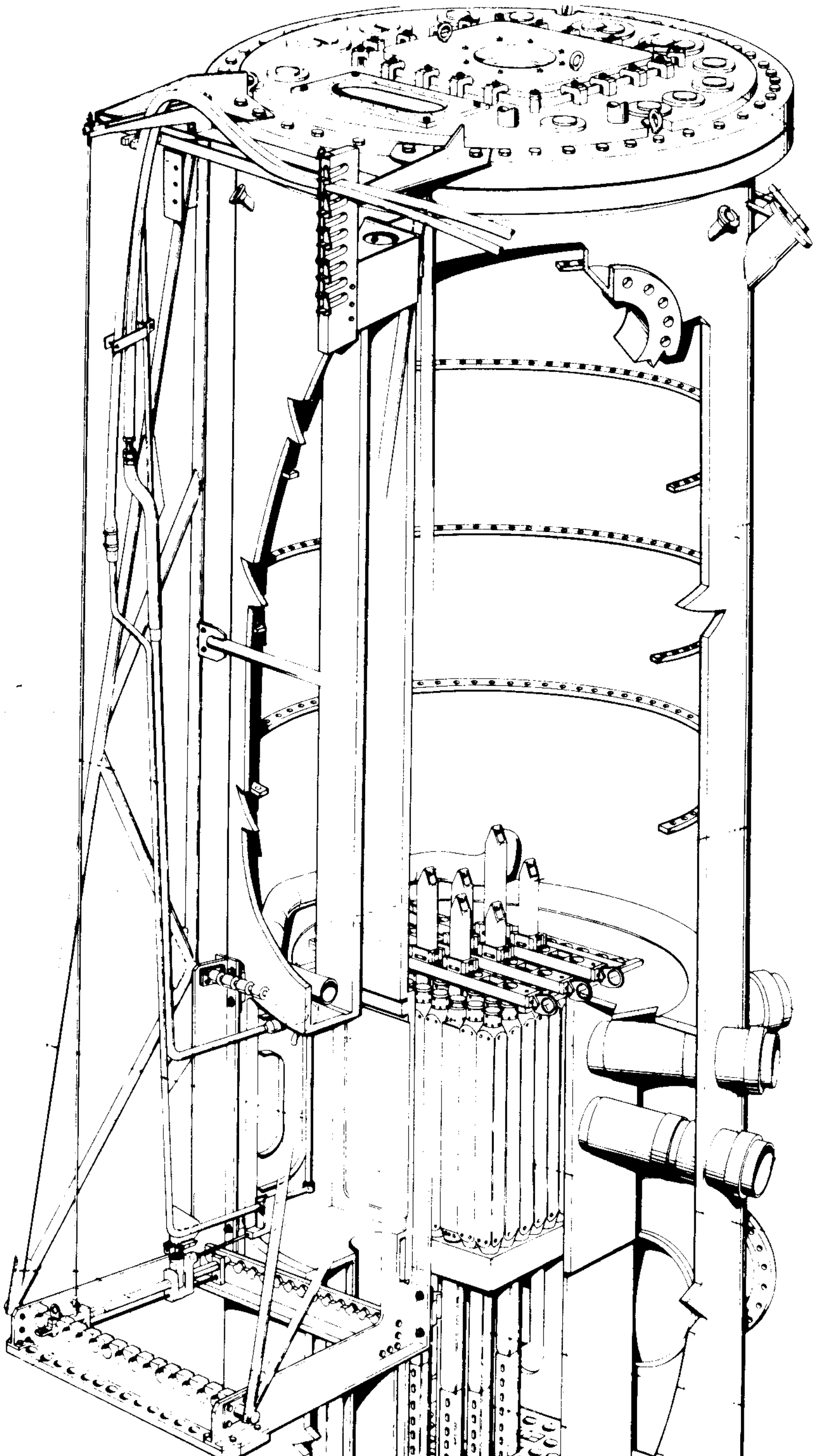
Special attention is being drawn on the facilities recently developed in the field of direct in-pile measurement of mechanical properties of various nuclear materials exposed to high neutron flux densities.

2. PARTICULAR FEATURES OF THE HIGH FLUX REACTOR AT THE JRC PETTEN

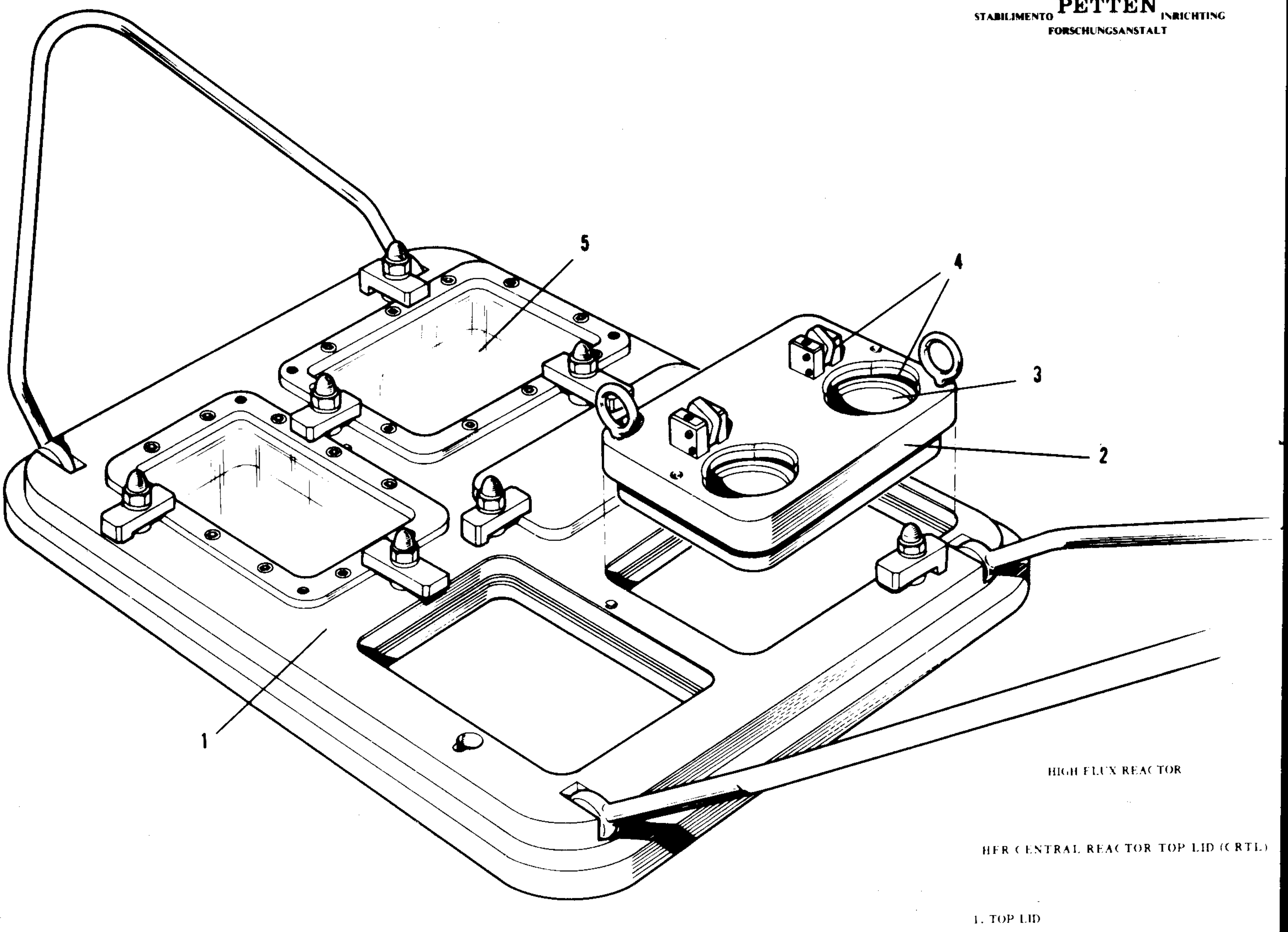
The four illustrations shown under this heading are:

- the reactor vessel, which is placed in the reactor pool. The vessel is sealed and pressurized to 3.6 kg/cm^2. 81 MTR fuel, reflector or filler elements, including 6 control rods, are placed in the core box. The light water primary reactor coolant and moderator enters at two opposite inlets underneath the cover plate. The control rods are operated from the basement guided by grid-bars on top of the core. Access from the pool to one outer face of the core box is provided by the pool side facility chimney and table.
- the central reactor top lid, which is part of the reactor cover plate. It is the main access for straight in-core irradiation devices in addition to the peripheral passages for bend-experiments.
- a vertical cross section of the reactor vessel, which shows the main possibilities of access to the high flux facilities and some accessory equipment.
- a view from the top of the reactor vessel onto the high flux facilities and the different ways of access. Typical nuclear data are indicated for the different experimental positions. They are defined as follows: Nuclear heating in W/g induced by combined nuclear radiation in a typical graphite drum; thermal neutron flux density values, reduced to the 2200 m/s energy equivalent according to the Westcott convention; fast neutron flux density is the equivalent fission neutron flux density.

It is to be noted that all supply lines, such as thermocouples, heaters, purging and sampling lines have to pas[s] the reactor cover plate and leave the reactor pool across or above its concrete walls.



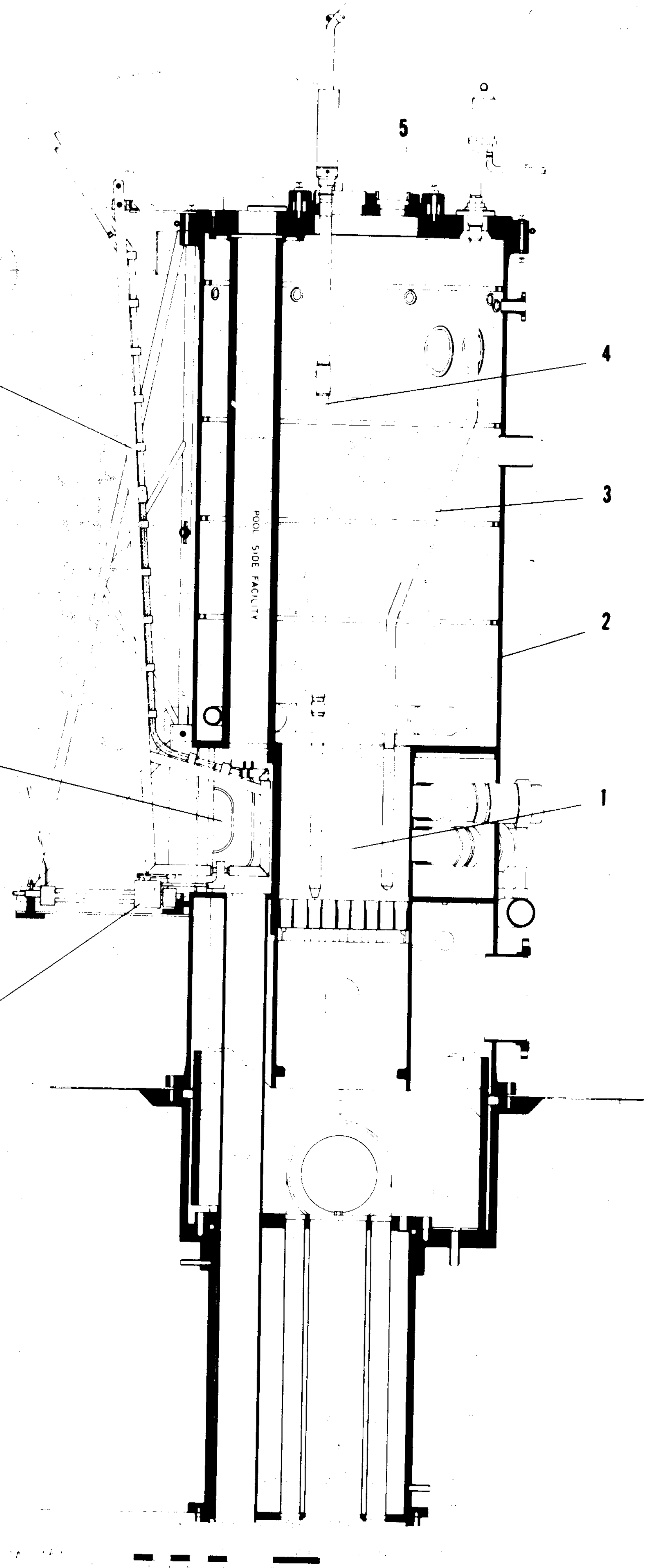
ETABLISSEMENT PETTEN ESTABLISHMENT
STABILIMENTO INRICHTING
FORSCHUNGSANSTALT



HIGH FLUX REACTOR

HFR CENTRAL REACTOR TOP LID (CRTL)

1. TOP LID
2. PLUG
3. PASSAGE FOR EXPERIMENTS
4. BAJONET - LOCK
5. INSPECTION PLUG



HIGH FLUX REACTOR
CROSS SECTION OF VESSEL

1. CORE AND REFLECTOR
2. REACTOR VESSEL
3. REFLECTOR IRRADIATION DEVICE
4. IN-CORE IRRADIATION DEVICE
   ALT. WITH VERT. DISPL. UNIT
5. CENTRAL REACTOR TOP LID
6. PSF STANDARD CARRIER
7. POOL SIDE FACILITY
8. HORIZONTAL DISPL. UNIT

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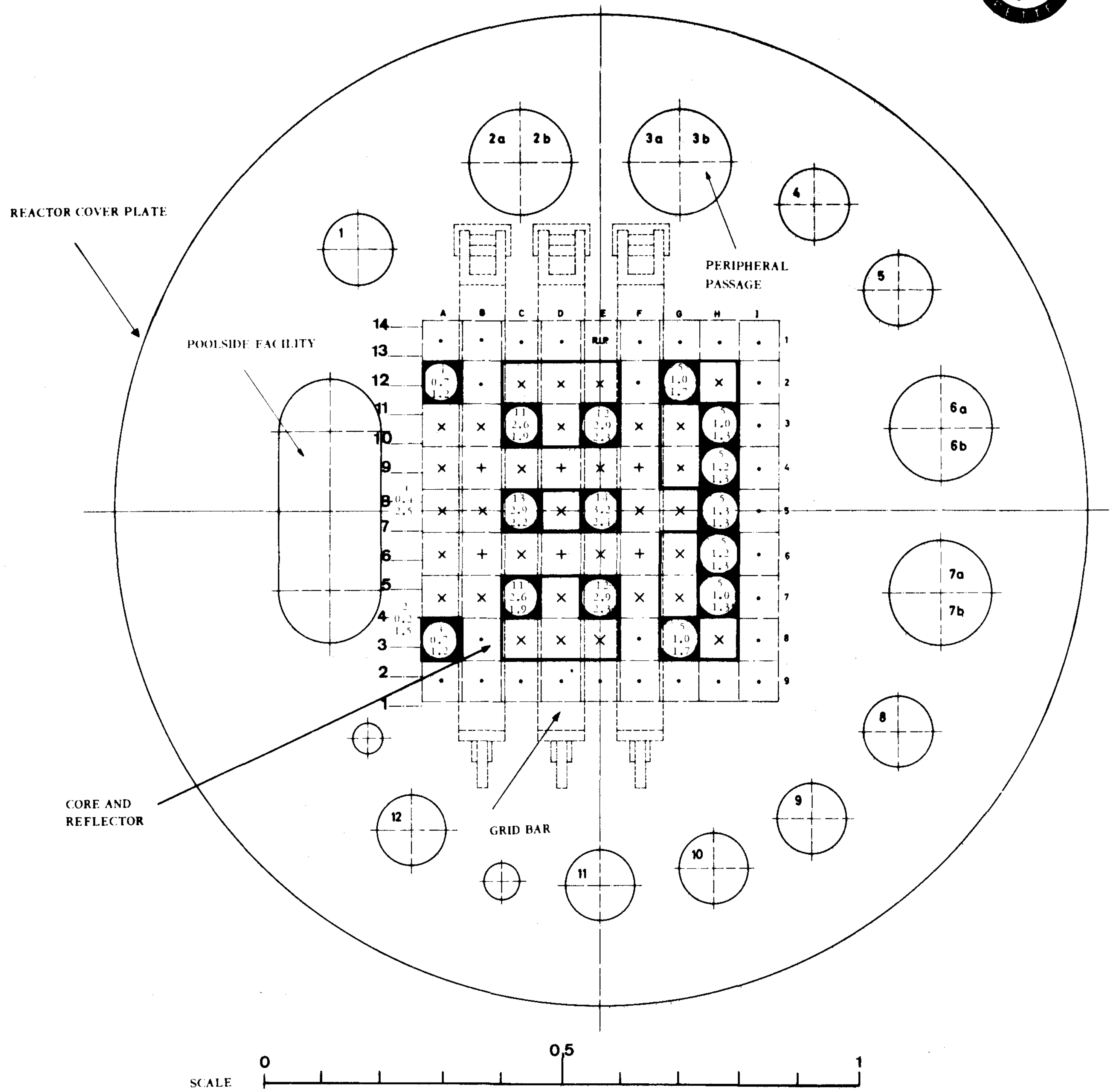

HIGH FLUX REACTOR

HIGH FLUX
IRRADIATION
FACILITIES

▭	ACCESS BY CENTRAL REACTOR TOP LID
+	CONTROL ROD
•	Be-ELEMENT
×	FUEL-ELEMENT
▣	EXPERIMENT POSITIONS

5 — NUCLEAR HEATING (W/g GRAPHITE)
1.2 — FAST FLUX DENSITY $\times 10^{14}$ ($n.cm^{-2}$ sec^{-1})
1.3 — THERMAL FLUX DENSITY $\times 10^{14}$ ($n.cm^{-2}$ sec^{-1})
PEAK VALUES

REF EUR
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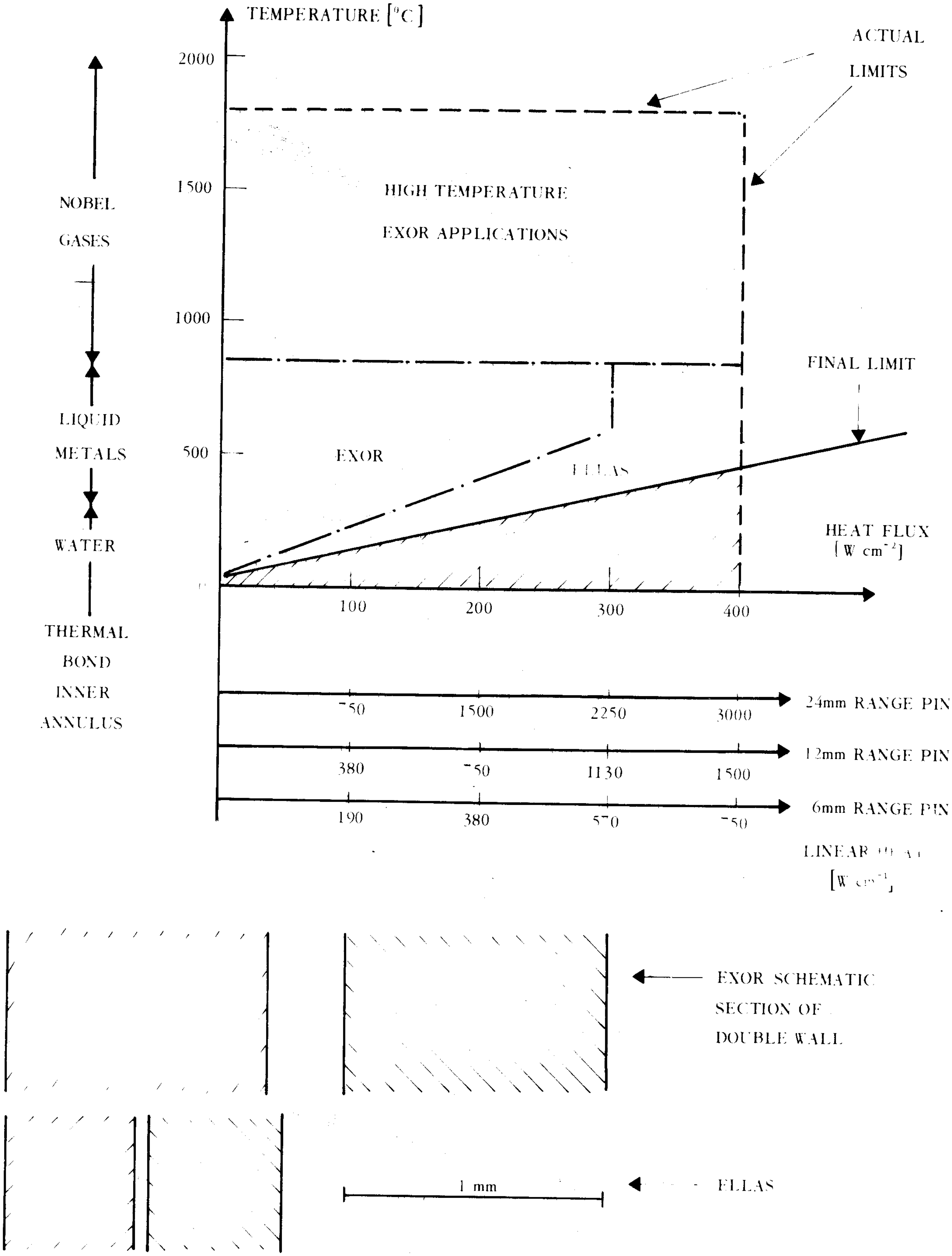
3. SURVEY OF AVAILABLE IRRADIATION DEVICES

This chapter is divided into three sections, displaying devices, which are mainly used for irradiation testing of fissile materials, non fissile or structural materials, and for in-pile measurement of mechanical properties of various nuclear materials. The chapters are preceeded by explanatory notes and information on developments presently engaged. Devices are described by an illustration and a corresponding specification sheet.

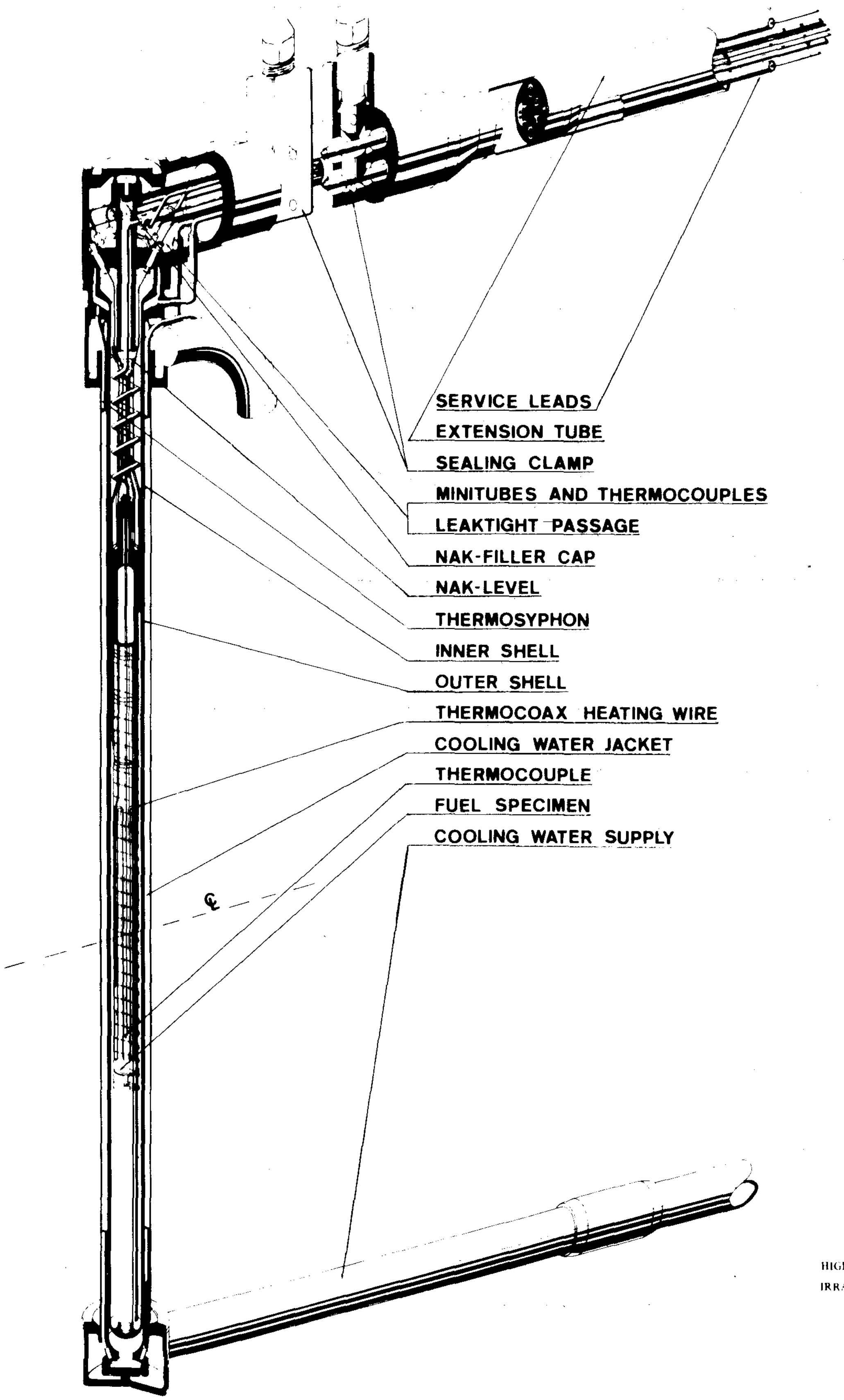
3.1 Irradiation devices for fissile materials

Due to the hazard of contamination by fission products, double containment is normally required for irradiations of fissile material in the HFR. The opposite scheme shows the general operation fields of double wall capsules.

In the following two double wall capsules, EXOR and ELLAS are presented as well as the flow diagramme of a fission gas release measurement circuit which has been operated satisfactorily in conjunction with a 1500^{o}C coated particle irradiation capsule.



DOUBLE WALL CAPSULES OPERATION FIELDS



HIGH FLUX REACTOR
IRRADIATION DEVICES
EXOR

IRRADIATION DEVICE SPECIFICATION SHEET.

Designation :	EXOR
Application :	Irradiation of fissile material
Reactor positions:	Pool Side Facility alternatively core or reflector
Basic concept :	double wall capsule; gas gap between walls; inner thermal bonding by liquid metal or rare gas; open cooling circuit.

Range of utilisation:

Specimen length :	400 mm	
Specimen diameter :	5 ÷ 20 mm (max. 60 mm)	
Heat dissipation :	800 W/cm	
Cladding temperature:	> 500°C	
Peak flux thermal x) :	2.6×10^{14} cm^{-2} s^{-1}	x) in core
Peak flux fast x) :	3.1×10^{14} cm^{-2} s^{-1}	

Special features:

Thermal calibration by electric simulation heater
Measurement of central fuel temperature
Measurement of cladding temperature
Measurement of fission gas pressure built up
Measurement of fission gas volume
Control of fission rate by Horizontal Displacement Unit
Programmed thermal cycling by H.D.U.
Temperature control by variation of gas mixture.

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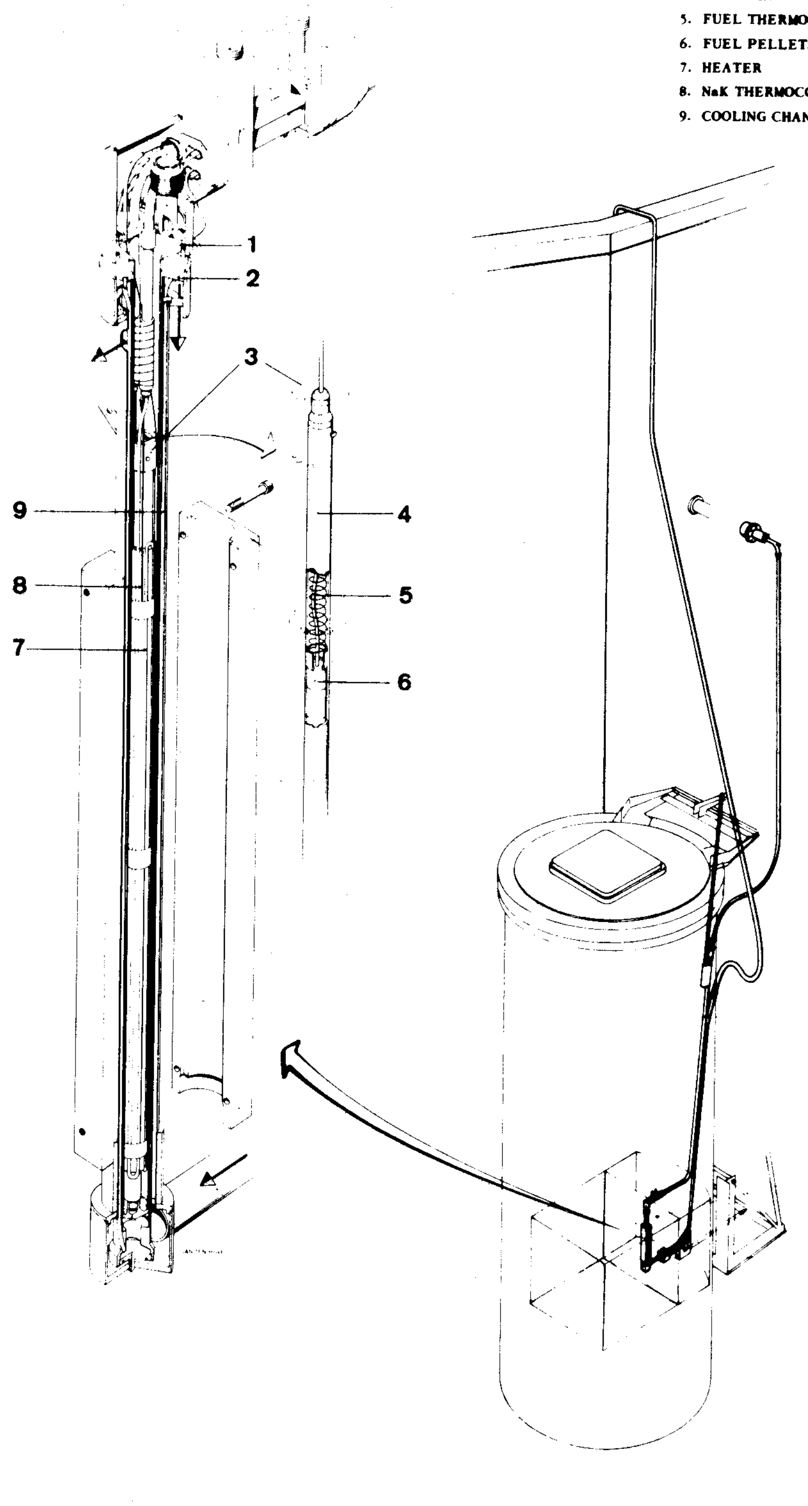
HIGH FLUX REACTOR

IRRADIATION DEVICES

ELLAS K 1

1. INNER CAN
2. OUTER CAN
3. SHROUD
4. FUEL PIN
5. FUEL THERMOCOUPLE
6. FUEL PELLETS
7. HEATER
8. NaK THERMOCOUPLES
9. COOLING CHANNEL



IRRADIATION DEVICE SPECIFICATION SHEET.

Designation	:	ELLAS
Application	:	Irradiation of fissile material
Reactor positions	:	Pool Side Facility alternatively core or reflector
Basic concept	:	double wall capsule; gas gap between walls; inner thermal bonding by liquid metal or rare gas; open cooling circuit.

Range of utilisation:

Specimen length	:	400 mm
Specimen diameter	:	5 ÷20 mm (max. 60 mm)
Heat dissipation	:	1500 W/cm
Cladding temperature	:	>300°C
Peak flux thermal x)	:	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast x)	:	3.1×10^{14} cm^{-2} s^{-1}

x) in core

Special features:

Thermal calibration by electric simulation heater
Measurement of central fuel temperature
Measurement of cladding temperature
Measurement of fission gas pressure built up
Measurement of fission gas volume
Control of fission rate by Horizontal Displacement Unit
Programmed thermal cycling by H.D.U.
Temperature control by variation of gas mixture.

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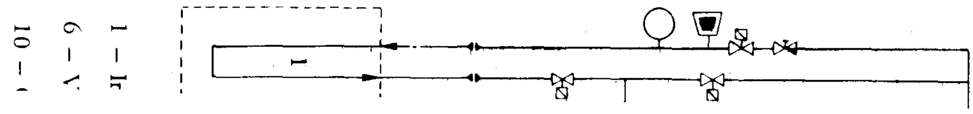
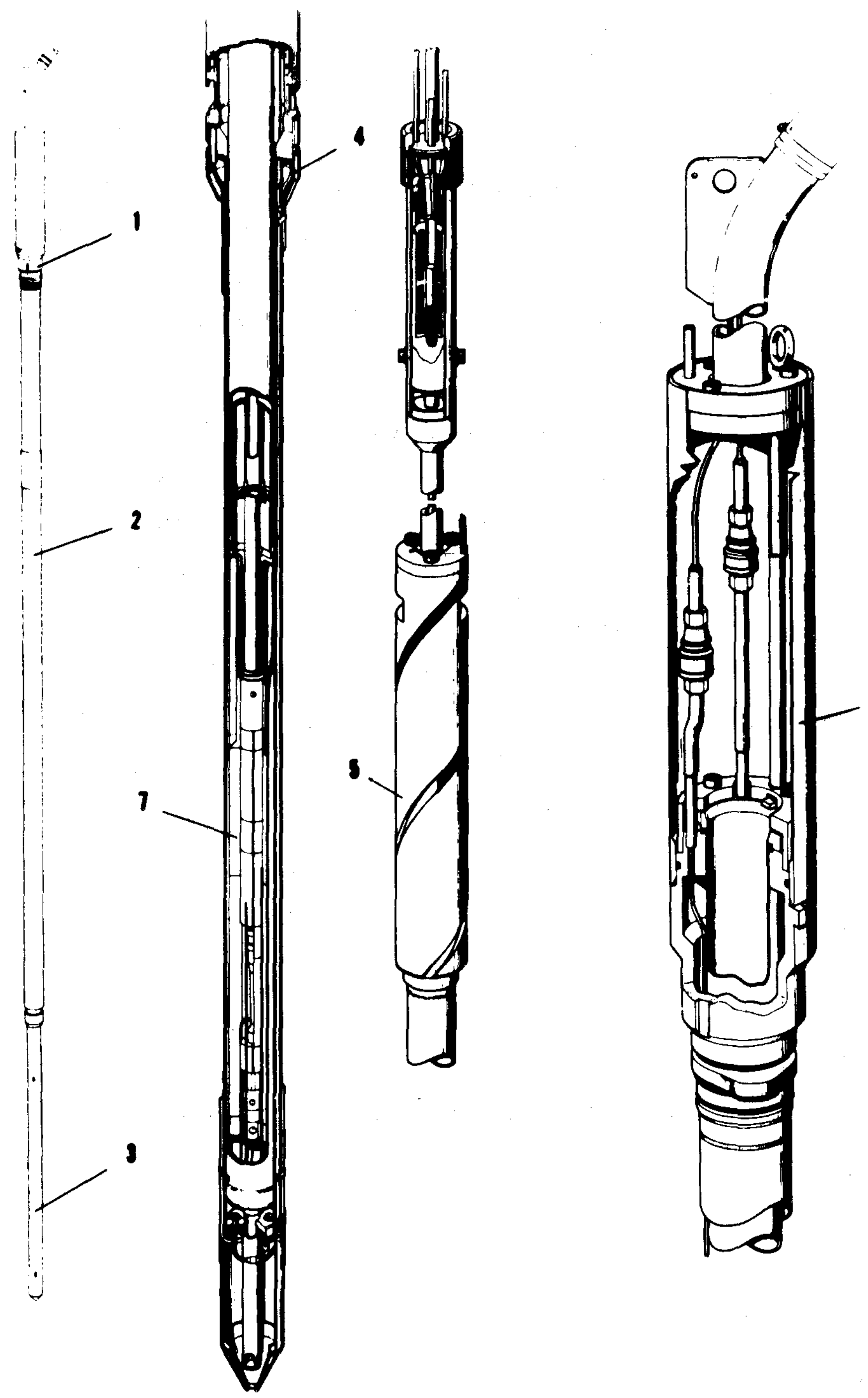


ETABLISSEMENT **PETTEN** ESTABLISHMENT
STABILIMENTO INRICHTING
FORSCHUNGSANSTALT



HIGH FLUX REACTOR
IRRADIATION DEVICES

RELOADABLE FACILITY

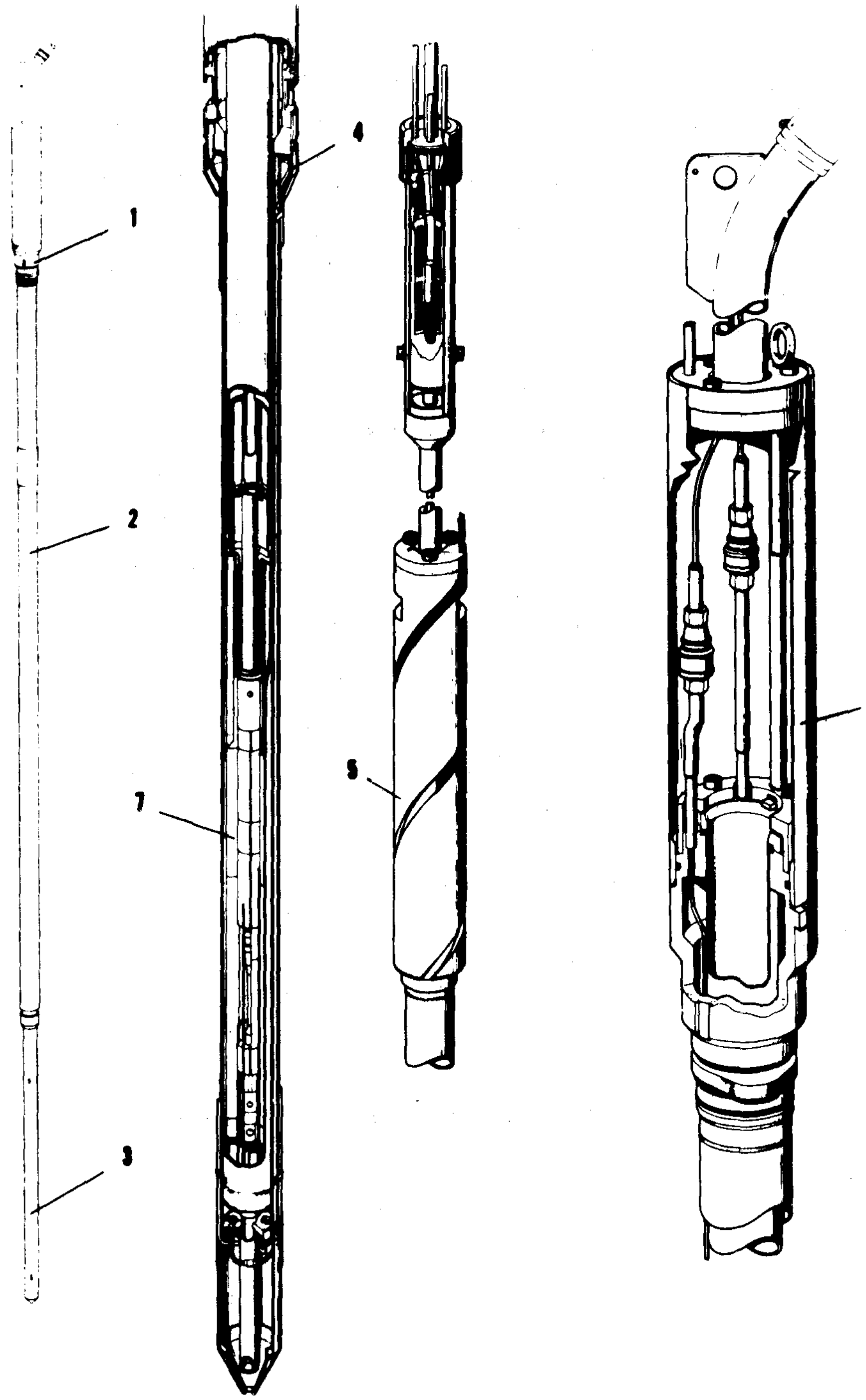
1. PASSAGE PLUG
2. EXTENSION TUBE
3. IN-PILE PART
4. GAS SUPPLY TUBING
5. SHIELD PLUG
6. CONNECTION BOX
7. TYPICAL INSERT (ME04

3.2 Irradiation devices for non fissile materials

Under this heading a selection of five irradiation devices is presented, which differ in temperature range, temperature accuracy, useful specimen volume and admissible nuclear heat load (limiting their use in in-core positions). These are the devices called REFA, GRIF, HEBE, HTR and DRAGON. The latter two, offer each four distinct temperature zones, individually controlled during the irradiation. Two improved devices are presently being built, DIRI and HTJ. The former is a thimble-insert design using a refined distribution of heat shields and gas gaps to achieve uniform temperature control by gas mixture on a sample holder to be operated in the 1000 ÷ 1400°C range. The latter is a thimble-insert design for four distinct temperature zones. Variation of gas mixture, vertical displacement and individual electrical heating are applied simultaneously to achieve optimum temperature control and specimen volume for low density materials irradiations in the centre core positions. The anticipated temperature range is comprised between 400 and 1200°C.

A simplified diagramme at the end of this section conveys a general impression on capsule temperature control.

ETABLISSEMENT PETTEN ESTABLISHMENT
STABILIMENTO INRICHTING
FORSCHUNGSANSTALT



HIGH FLUX REACTOR
IRRADIATION DEVICES

RELOADABLE FACILITY

1. PASSAGE PLUG
2. EXTENSION TUBE
3. IN-PILE PART
4. GAS SUPPLY TUBING
5. SHIELD PLUG
6. CONNECTION BOX
7. TYPICAL INSERT (ME04

IRRADIATION DEVICE SPECIFICATION SHEET.

Designation :	REFA
Application :	Multipurpose reloadable facility
Reactor positions:	core or reflector, access by CRTL
Basic concept :	Standard thimble for various irradiations, to be used with special inserts; gas supply lines for temperature control incorporated; cooling reactor primary coolant.

Range of utilisation:

Useful length :	600 mm
Useful diameter :	up to 54 mm
Heat dissipation:	up to 80 W/cm^3 (diam. dependent)
Temperature range:	200 to 2000°C
Peak flux thermal	2.6×10^{14}
Peak flux fast :	3.1×10^{14}

Special features:

May be used for all kind of irradiation, fissile or non fissile, sodium bond or inert gas atmosphere.

Choice of various diameters, shield plugs and passages.

Vertical displacement unit (coarse 100 mm)

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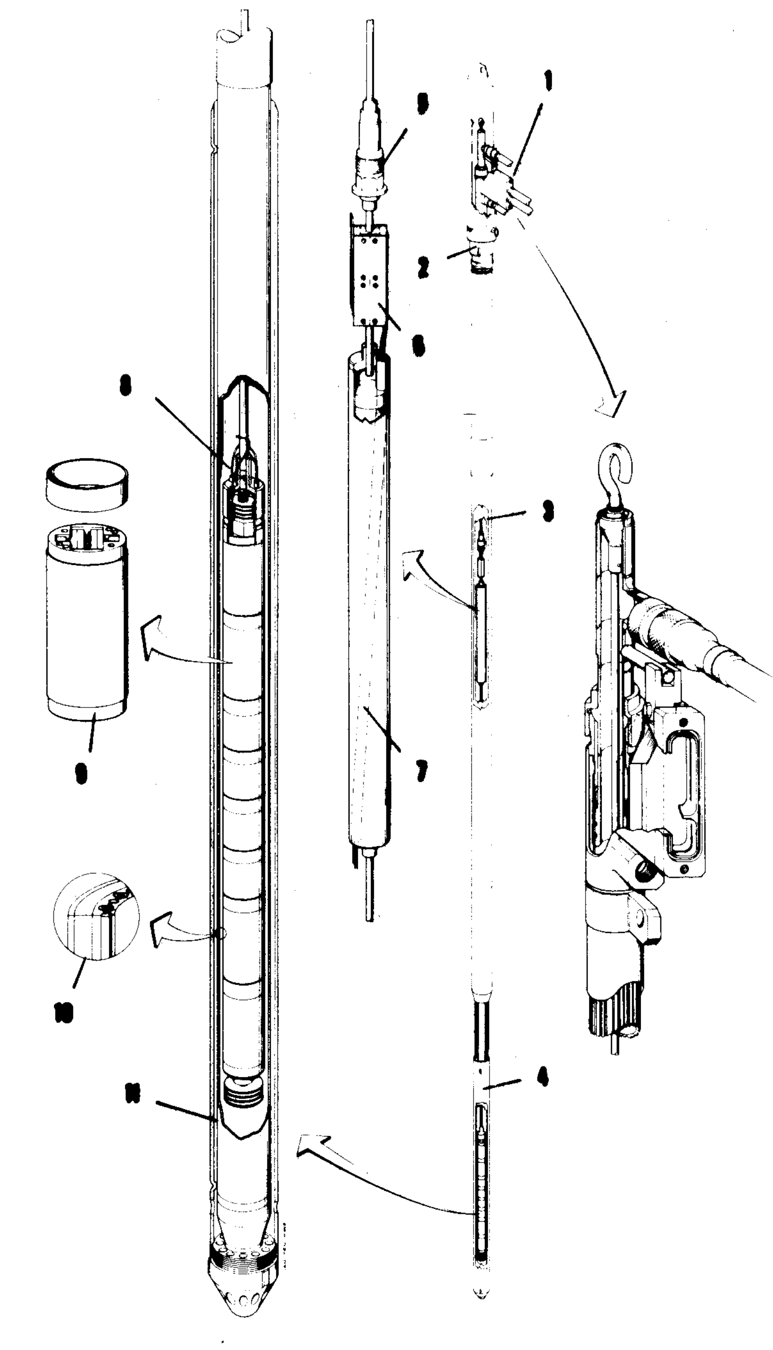
ETABLISSEMENT ESTABLISHMENT
STABILIMENTO **PETTEN** INRICHTING
FORSCHUNGSANSTALT

HIGH FLUX REACTOR
IRRADIATION DEVICES

RELOADABLE FURNACE GRIF

1. RIG HEAD
2. PASSAGE PLUG
3. EXTENSION TUBE
4. IN-PILE PART
5. HANSEN COUPLING
6. THERMOCOUPLE CONNECTOR
7. SHIELD PLUG
8. THERMOCOUPLES
9. SAMPLE CARRIER
10. HEATER SECTION
11. COOLING CHANNEL



IRRADIATION DEVICE SPECIFICATION SHEET.

Designation	:	GRIF
Application	:	Irradiation of non fissile and fissile material
Reactor positions	:	core or reflector, access by CRTL or peripheral passage
Basic concept	:	Thimble-insert principle, thus reloadable; six hairpin heaters, spraycoated, independent, part of thimble structure, provide homogeneous temperature control; cooling by reactor primary water;

Range of utilisation:

Useful length	:	415 mm
Useful diameter	:	30 mm
Heat dissipation	:	150 W/cm^3
Temperature range	:	200 ÷ 900°C
Peak flux thermal	:	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast	:	3.1×10^{14} cm^{-2} s^{-1}

Special features:

Multi purpose rig

Temperature control by variation of gas mixture and electrical heating to ± 3°C in space and time

Electric heater power 500 W/cm

Inert gas atmosphere up to 80 kp cm^{-2}

Double containment.

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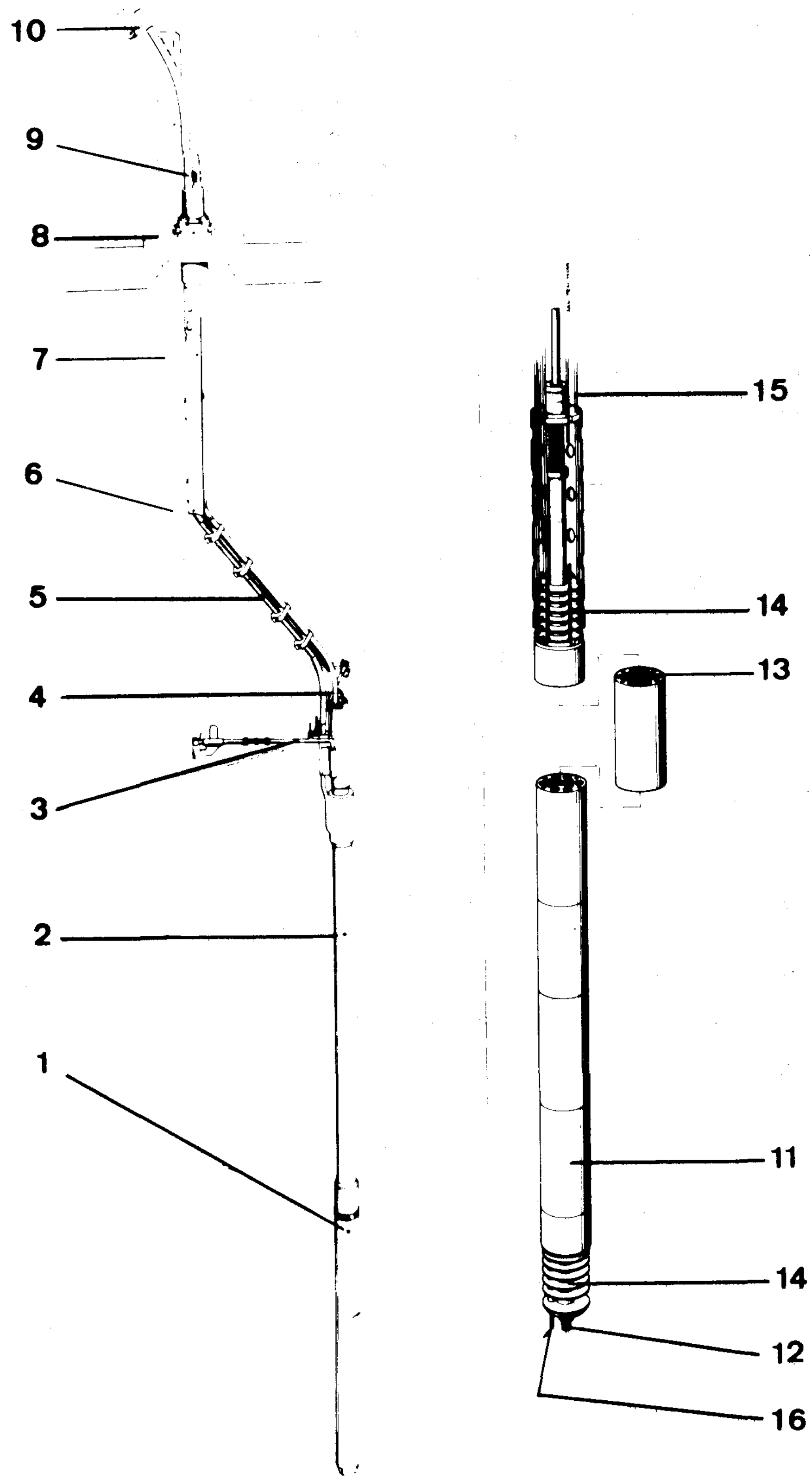

1. Furnace
2. Extension tube
3. Link-rod
4. Sealing plug
5. Flexible for furnace
6. Flexible hose for sample holder
7. Cover-link
8. Adjustable leak-tight cover-passage
9. Thermocouple-connector
10. Connection box
11. Graphite drums
12. Niobium support-rod
13. Holes for samples, flux detectors, thermocouples
14. Niobium screens
15. Niobium minitube

IRRADIATION DEVICE SPECIFICATION SHEET.

Designation	:	HTR
Application	:	Irradiation of non fissile materials
Reactor positions	:	core or reflector, access by peripheral passage
Basic concept	:	Bend extension tube with detachable in pile part of thimble, metallic joint; 4 individually reloadable carriers, 4 separate heaters for zonal temperature control; cooling of thimble by primary reactor coolant.

Range of utilisation:

Useful length	:	4 x 67 mm
Useful diameter	:	44 mm (minus cut-off)
Heat dissipation	:	15 W/cm^3 (carrier average)
Temperature range	:	500, 600 ÷ 800, 900°C
Peak flux thermal	:	1.7×10^{14}
Peak flux fast	:	1.2×10^{14}

Special features :

Especially designed for graphite irradiation in the medium temperature range.
Four individually controlled temperature zones.
Temperature control by electrical heating and variation of gas mixture.

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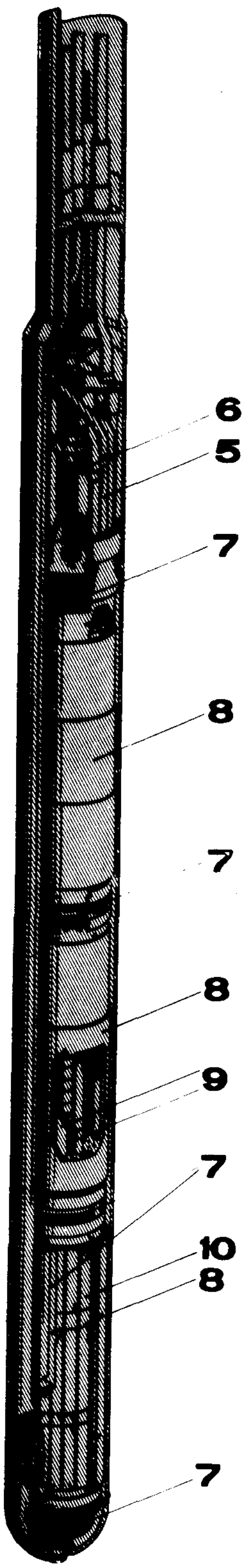
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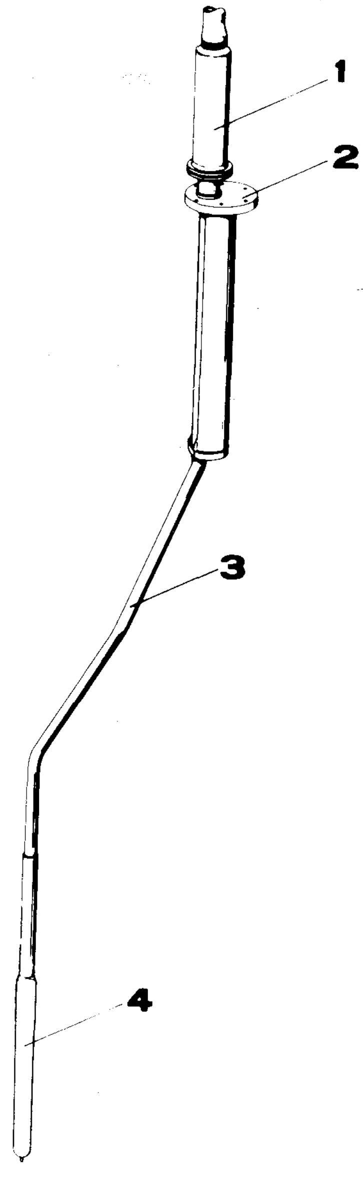
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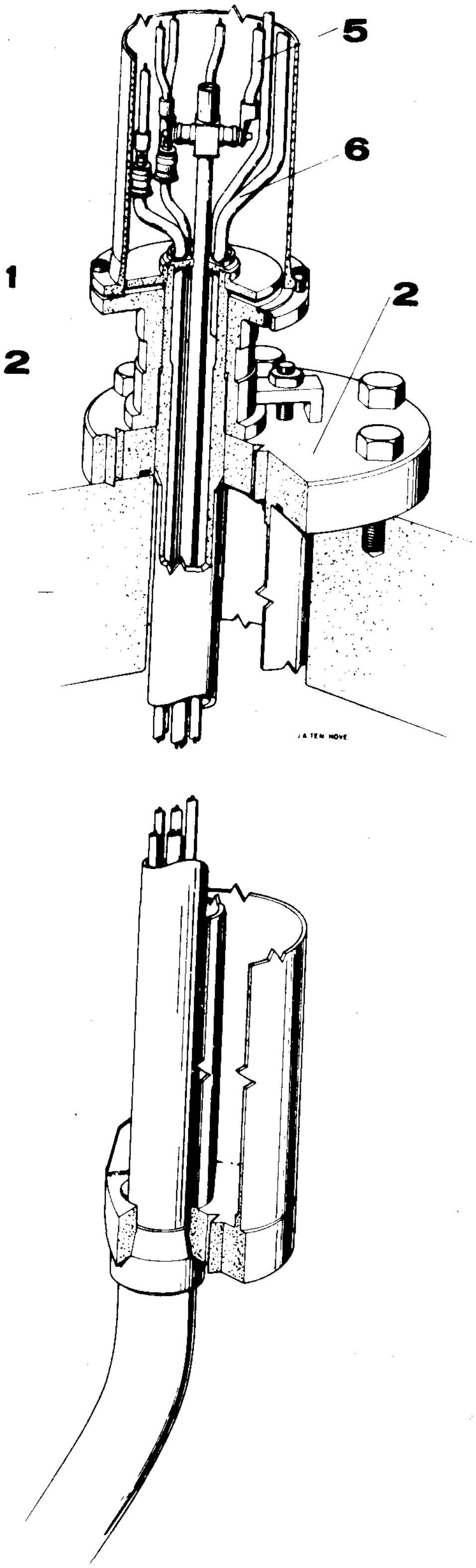
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IRRADIATION DEVICE SPECIFICATION SHEET

Designation	:	DRAGON
Application	:	Irradiation of non fissile materials
Reactor positions	:	Core or reflector, access by peripheral passage.
Basic concept	:	Bend extension tube, non reloadable; 4 separate heaters for temperature control in 4 zones, by molybdenum wires, insulated by alumina tubes in graphite formers; cooling by reactor primary water;

Range of utilisation:

Useful length	:	4 x 120 mm
Useful diameter	:	44 mm
Heat dissipation	:	25 W/cm^3 (carrier average)
Temperature range	:	400 ÷ 700, 600 ÷ 900, 800 ÷ 1200, 1000 ÷ 1400°C
Peak flux thermal	:	2.6×10^{14}
Peak flux fast	:	3.1×10^{14}

Special features:

Especially designed for graphite irradiations in the high temperature range. Large useful volume.
Four individually controlled temperature zones.
Temperature control by electrical heating and variation of gas mixture.

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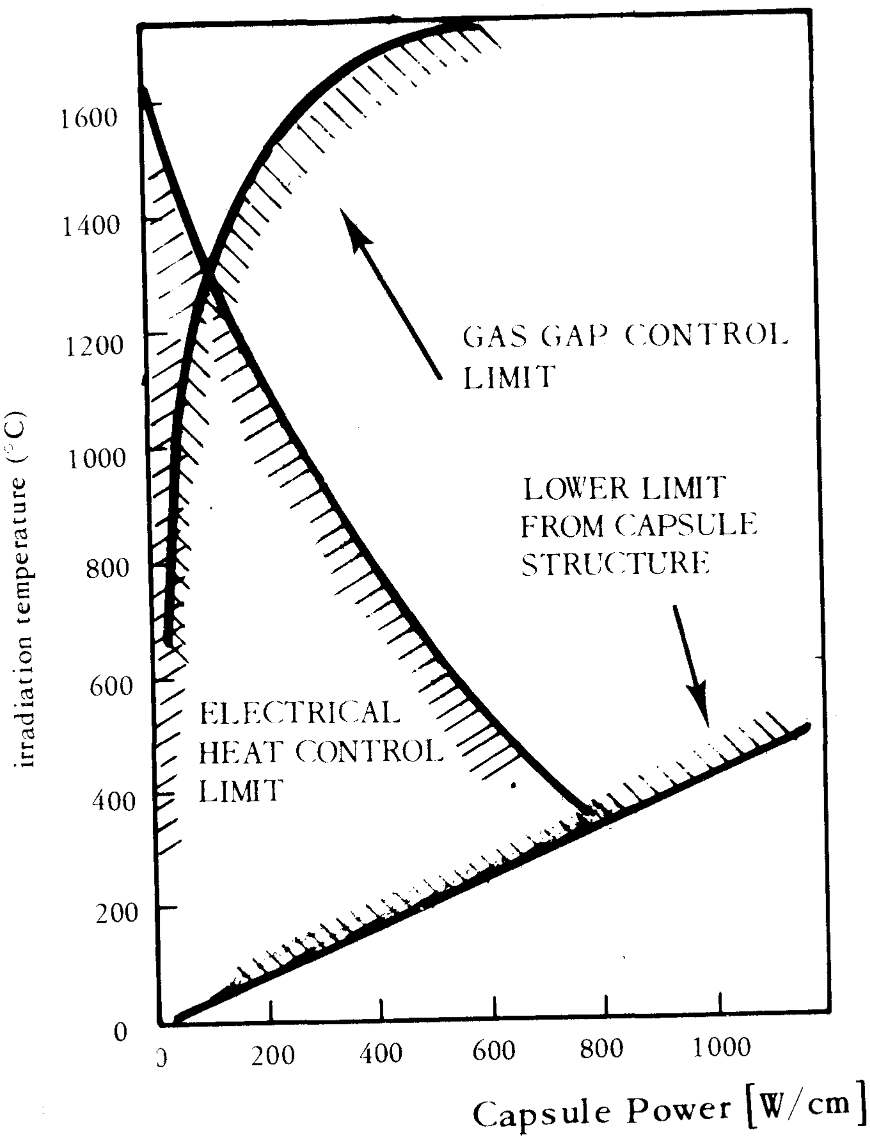


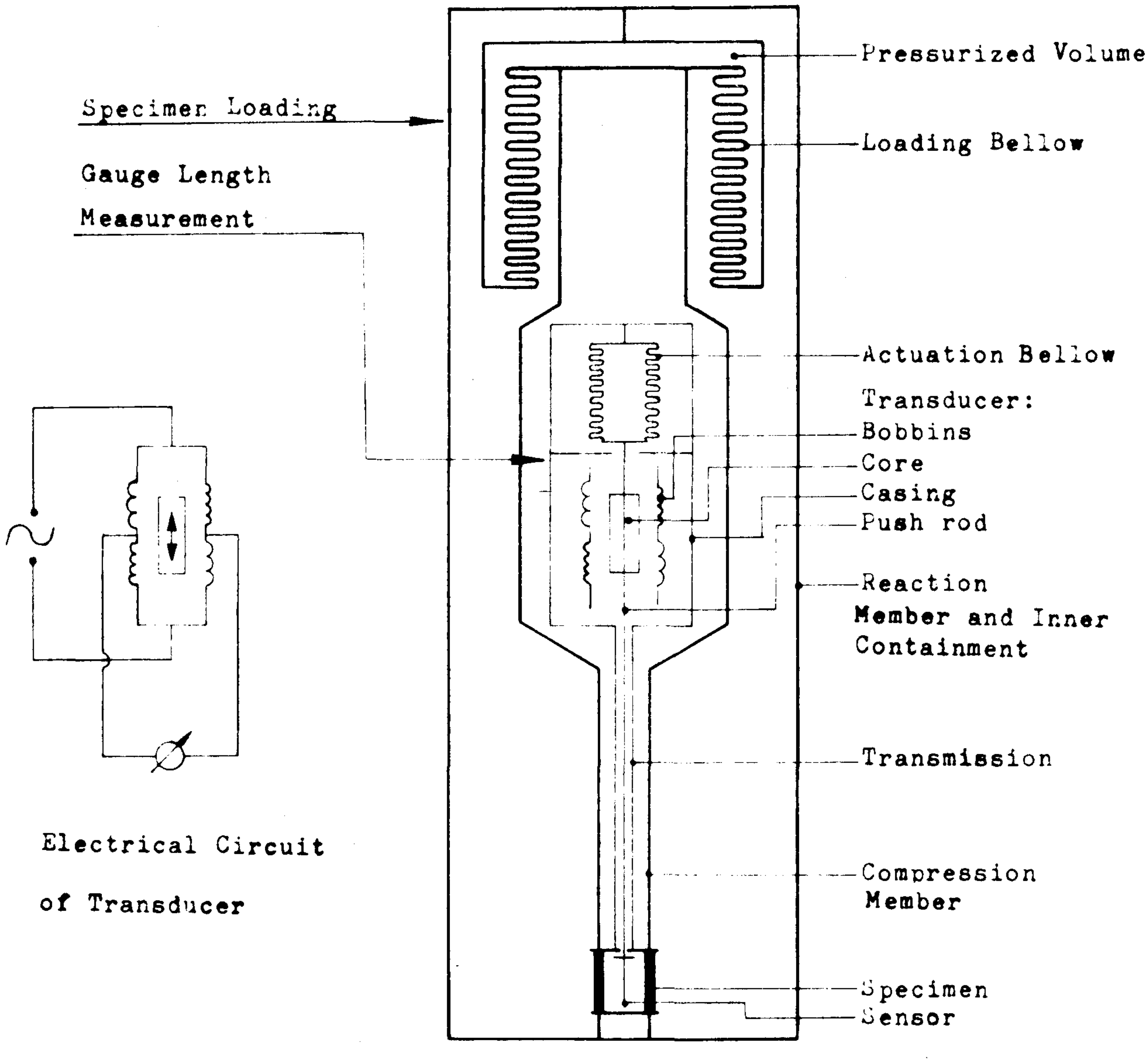
LIMITS OF CAPSULE TEMPERATURE CONTROL.

3.3 Irradiation devices for in-pile measurement of mechanical properties of nuclear materials

In this section the results of recent developments in advanced nuclear materials testing are presented. From the design point of view, a difference is made between compressive or tensile testing. From the materials point of view we distinguish ceramic fuel, graphite or carbon base materials, cladding or other structural materials, because they differ in heat release, strain, and required temperature accuracy. Properties considered under this heading are creep rate, swelling or shrinkage, yield stress, ultimate stress, Young's modulus and the coefficient of thermal expansion.

Two main components of these facilities are the loading and the measuring system. For the former a satisfactory solution has been found using pressurized calibrated bellows to apply loadings between 0 and 3000 N. The measuring system consists of a differential gauge length measuring system in conjunction with an inductive linear differential transducer. The accuracy obtained is evaluated to be better than 10^{-6} m.

Actually the graphite creep assembly is operational, a fuel creep assembly is being built, and a creep assembly for cladding materials is in the predesign stage.



Scheme of Fuel Creep Assembly.

IRRADIATION DEVICE SPECIFICATION SHEET

Designation	:	Fuel Creep Assembly
Application	:	Measurement of elongation of fissile specimen during neutron irradiation under variable loading, fission rate and specimen temperature.
Reactor position	:	pool side facility, alternatively core or reflector.
Basic concept	:	Hollow cylindrical specimen compressed between molybdenum members; stressed by pressurized bellow; differential gauge length measured with inductive linear displacement transducer; temperature control by gas gaps and variation of gas mixture; specimen thermal bonding NaK or noble gases.

Range of utilisation:

Total gauge length	:	20 mm
Compressive load	:	0 to 3000 N
Temperature range	:	$> 800^{\circ}C$
Transducer coarse	:	$\pm$ 2.5 mm
Transducer resolution	:	$< 10^{-4}$ mm
Peak flux thermal x)	:	2.8×10^{14}
Peak flux fast x)	:	0.6×10^{14}

x) in PSF

Special features:

Controlled load by pressure line to bellow.

Temperature variation by gas mixture.

Fission rate control by horizontal displacement unit.

Transducer remote from specimen.

Differential gauge length measurement by bellow actuated sensor.

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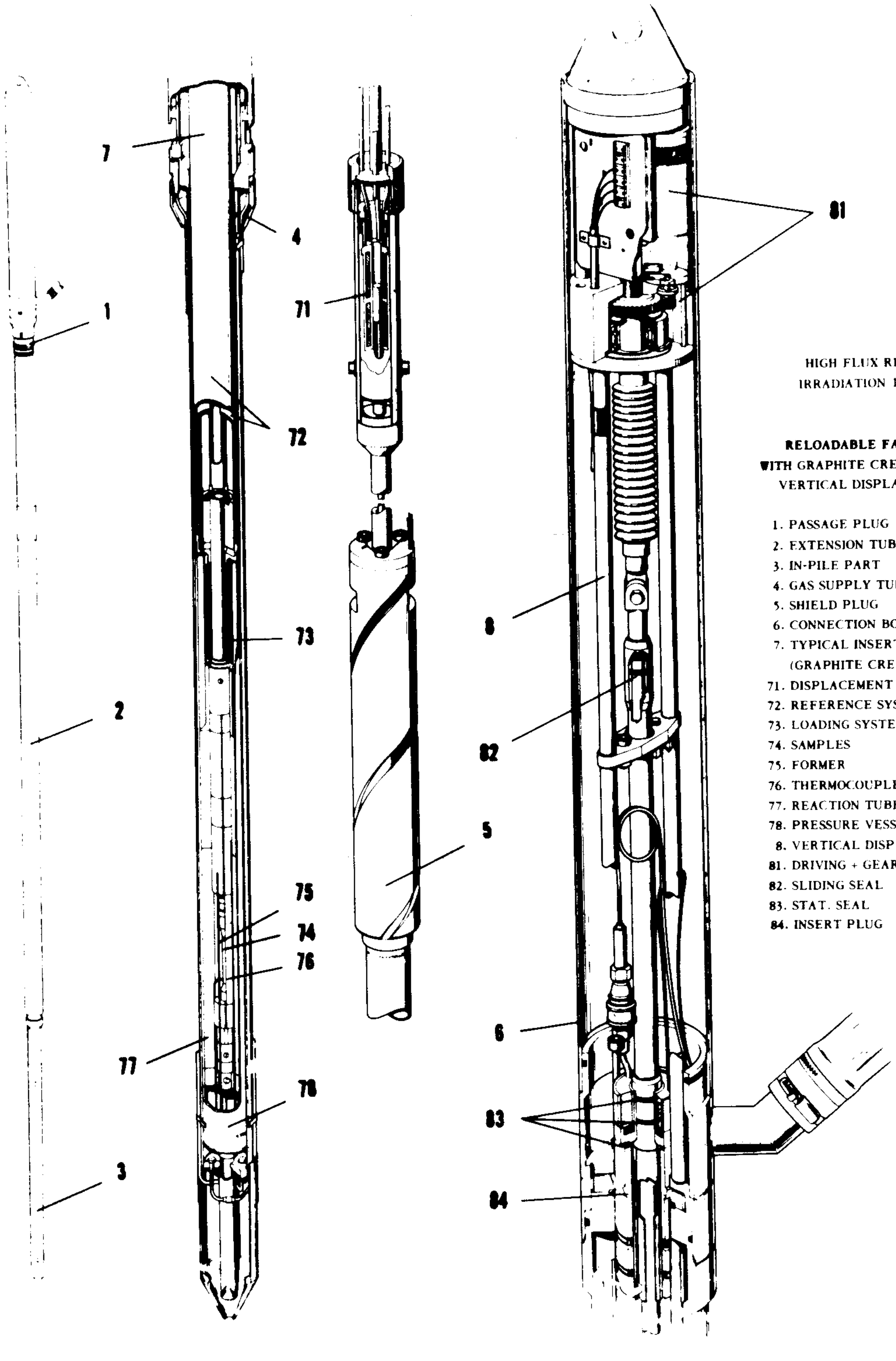

HIGH FLUX REACTOR
IRRADIATION DEVICES

RELOADABLE FACILITY REFA
WITH GRAPHITE CREEP MACHINE AND
VERTICAL DISPLACEMENT UNIT

1. PASSAGE PLUG
2. EXTENSION TUBE
3. IN-PILE PART
4. GAS SUPPLY TUBING
5. SHIELD PLUG
6. CONNECTION BOX
7. TYPICAL INSERT
(GRAPHITE CREEP MACHINE ME04)
71. DISPLACEMENT TRANSDUCER
72. REFERENCE SYSTEM
73. LOADING SYSTEM
74. SAMPLES
75. FORMER
76. THERMOCOUPLES
77. REACTION TUBE
78. PRESSURE VESSEL
8. VERTICAL DISPLACEMENT UNIT
81. DRIVING + GEARING
82. SLIDING SEAL
83. STAT. SEAL
84. INSERT PLUG

REF EUR
R 1394

IRRADIATION DEVICE SPECIFICATION SHEET.

Designation	:	Graphite Creep Machine
Application	:	Tensile creep measurements on graphite under irradiation
Reactor positions	:	core or reflector, using Refa thimble
Basic concept	:	Pile of graphite specimen, linked by clamps, stressed by pressurized bellow;
		strain measurement by inductive linear displacement transducer; temperature control by stepped gas gaps and variation of gas mixture.

Range of utilisation:

Total gauge length	:	200 mm
Tensile load	:	100 kp
Temperature range	:	600 to 900^{o}C
Transducer coarse	:	$\pm$ 2.5 mm
Transducer resolution	:	$< 10^{-3}$ mm
Peak flux thermal	:	2.6×10^{14}
Peak flux fast	:	3.1×10^{14}

Special features:

Controlled load by pressure line to bellow

Transducer remote from specimen

Differential gauge length measurement by bellow actuated sensor

Vertical Displacement Unit for temperature adjustment.

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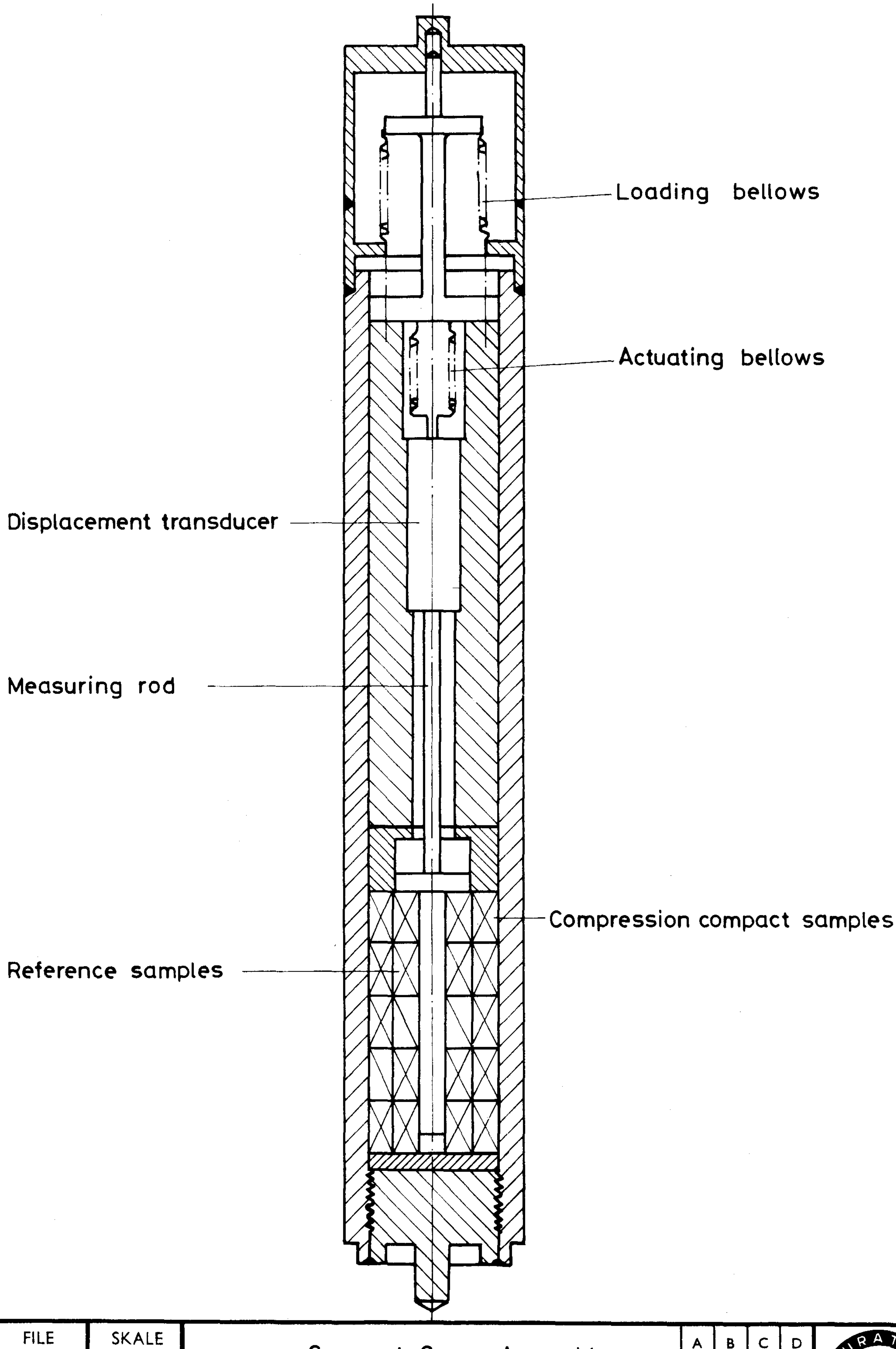

FILE	SKALE	Compact Creep Assembly	A	B	C	D
			E	F	G	H

Utilisation

DATE
BY

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IRRADIATION DEVICE SPECIFICATION SHEET

Designation	:	Compact Creep Assembly
Application	:	Compressive creep measurements on compact specimen under irradiation
Reactor positions	:	Core or reflector, using Refa thimble
Basic concept	:	Hollow cylindrical specimens compressed between molybdenum members; stressed by pressurized bellow; differential gauge length measured with inductive linear displacement transducer; temperature control by gas gaps and variation of gas mixture.

Range of utilisation:

Total gauge length	:	100 mm
Compressive load	:	0 to 3000 N
Temperature range	:	600 to 1200 ^{o}C
Transducer coarse	:	$\pm$ 2.5 mm
Transducer resolution	:	$< 10^{-4}$ mm
Peak flux thermal	:	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast	:	3.1×10^{14} cm^{-2} s^{-1}

Special features:

Controlled load by pressure line to bellow.

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Alfred Nobel

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